Spectral Similarity Index (SSI) Overview

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INTRODUCTION

The Academy of Motion Pictures Arts and Sciences has developed the Spectral Similarity Index (SSI) a measure of predicting the rendering quality of light sources. SSI is intended to address the issues with existing indices which are inappropriate for evaluating solid-state lighting in motion picture applications.

This report reviews the spectral characteristics of solid-state lighting such as LEDs, and how they can present problems for photography and cinematography. It describes how existing quantifications of rendering quality, such as the Color Rendering Index (CRI), have limitations that can make them poor measures of LED-sourced rendering quality. SSI is introduced and described, and the details of its calculation are presented.

BACKGROUND

As new lighting technologies were developed to supplement daylight and tungsten incandescent sources for cinematography, the need for a measure of the faithfulness of color rendition became important. Various indices have been developed to measure the ability of a light source to produce accurate rendered colors. The most common is the Color Rendering Index, which is based on the CIE “standard observer” (intended to typify human color perception) for “seeing” the colors. Some indices, such as the Television Lighting Consistency Index (TLCI), are based on a defined spectral sensitivity, which for TLCI is an average spectral sensitivity of a variety of cameras used for broadcast television. However, digital cinema cameras can have spectral sensitivities that are quite different from those of television cameras, different than the eye’s response, and different from each other. The inadequacies of these existing indices can become particularly evident when applied to solid-state lighting (SSL), which in recent years has gained popularity in cinematography for the numerous benefits it offers such as low power consumption, less heat generated that with incandescent luminaires, smaller size and flexible configurations, and greater stability of color temperature with power variations. SSL generally refers to LED sources, but it also includes technologies such as OLED, electroluminescent, etc.

SOLID-STATE LIGHTING

The Solid State Lighting Project Committee of the Academy of Motion Picture Arts and Sciences’ Science and Technology Council had previously examined issues related to color errors in motion-picture photography caused by the differences in the spectral characteristics of LED sources as compared to tungsten-based incandescent lighting.

The spectral sensitivities of film emulsions, and of many digital cameras, are designed using “studio tungsten” and “photographic daylight” reference illuminants as described in ISO Standard 7589.[1] In contrast to the relatively smooth, unimodal spectral power distributions of blackbody emission, tungsten incandescence, and daylight (and the ISO standardizations of these sources), many solid-state sources are characterized by peaky, multimodal, or narrow-band spectral distributions. These spectral distributions can cause unpredictable and undesirable rendition (by both film and digital sensors), since film and digital cameras are all expressly designed to work with, and are indeed optimized for, standard tungsten and daylight sources.

MEASURING RENDERING QUALITY

The degree to which a non-incandescent source could mimic the faithful rendering of standard tungsten and daylight has typically been described by the Color Rendering Index (CRI)[2] and the correlated color temperature (CCT). However, CRI is based on the spectral sensitivity of human vision (the CIE 1931 “standard observer”[3]), and presumes the unimodality (non-“spikiness”) of incandescence. The CRI value is determined by the rendering of a small number of test colors, which are mostly of low saturation and do not include skin tones, through the CIE color matching functions. There is no standard for the spectral sensitivity curves of the red, green, and blue filters in single-chip digital cameras by which they create color images, and “peakiness” in LED spectra can interact with the differing sensitivities of cameras in unexpected ways that result in different camera models producing different color renditions of the same scene illuminated by the same SSL sources. This can yield undesirable appearance of skin, costumes, and props, even with LED sources with (misleadingly-) high CRI scores.

In 2007 the CIE set forth that an alternate index for color rendering should be established to address the deceptive CRI values that can occur when evaluating SSL sources. Two CIE workgroups have spent years working on the challenge, but so far a new index has not been published. The British Broadcasting Corporation (BBC) and European Broadcasting Union (EBU) have proposed the use of EBU Recommendation 137, the Television Lighting Consistency Index (TLCI), but this metric is based upon the spectral sensitivity of an idealized three-chip television camera and presented on a display with a color gamut as described in ITU-R Recommendation BT.709. As such, TLCI does not adequately account for the differing spectral sensitivities of single-chip cinema- or still-camera digital sensors. The Illuminating Engineering Society (IES) has proposed TM 30-15, “IES Method for Evaluating Light Source Color Rendition,” but this is also based on human vision and does not account for the variances in spectral sensitivity between the numerous digital cameras available to cinematographers today.

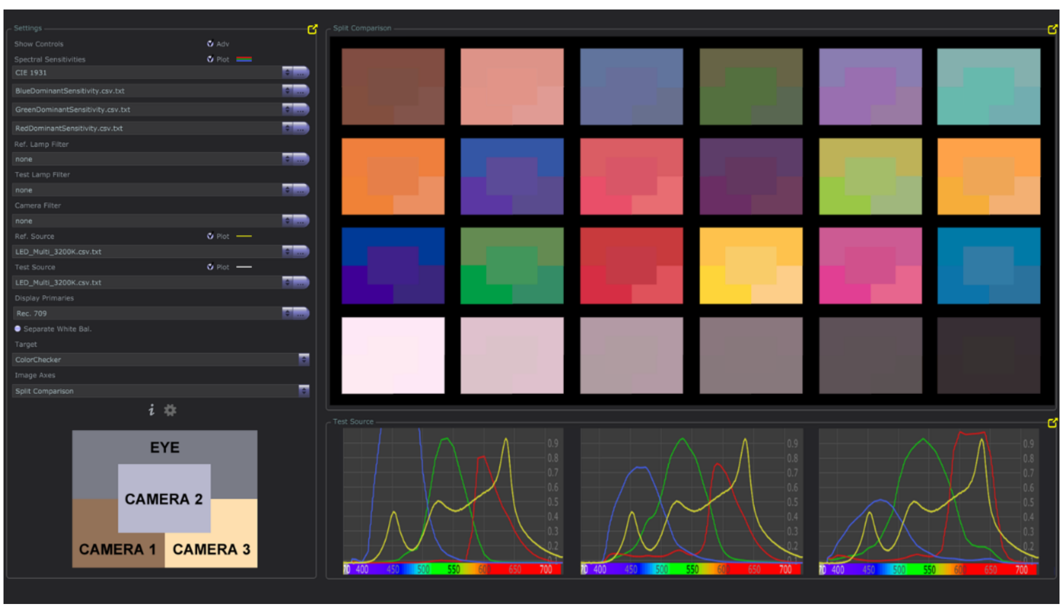

FIGURE 1. Segmented Macbeth chart demonstrating color-reproduction differences between three different cameras with the same light source.

Figure 1 is a simulation of how colors can be rendered differently when “seen” by the eye and different digital cinema cameras. The yellow curve in the three examples is an actual LED light source commonly used for cinematography. The red, green, and blue curves represent the spectral sensitivities of three commonly-used cameras. The color patches are those of a Macbeth Color Checker chart but rendered as seen by the eye and by each of the cameras. Each color patch is divided into four regions as illustrated in the key at the lower left of the figure. The upper region is the color as seen by the eye, and the remaining regions are as “seen” by the different cameras. Even though the spectrum of the source illustrated in Figure 1 has a CRI value of 92, it still results in obvious color rendering differences as seen by cameras with differing spectral sensitivities. This illustrates why CRI cannot be used as a reliable predictor of color-rendering accuracy for cameras with differing spectral sensitivities.

SSI

The Academy’s Solid State Lighting Project Committee, working with cinematographers, cinema lighting experts, lighting manufacturers, and lighting, imaging, and camera scientists and engineers, has developed an alternative index. The Project Committee concluded that an alternative to CRI was needed that was independent of camera sensitivities and the CIE standard observer since the spectral sensitivities of digital cinema cameras can vary widely from model to model, and none of them match that of the standard observer. The Project Committee determined that the only viable approach to defining an index that works for all cameras - as well for as human vision - was to remove spectral sensitivity from the equation and base the index solely on the light source’s spectral power emission at various wavelengths as compared to a known reference spectral power distribution. The idea being that if a source is “sufficiently similar” to that of the reference illuminants for which all film stocks and digital cameras are designed, then color rendering differences should appear proportionately less.

This new index is called the Spectral Similarity Index (SSI), and it can be thought of as a “confidence factor” for predictability of accurate color rendering, based upon how similar a source spectrum is to that of a reference illuminant (typically daylight or incandescent that closely approximates a blackbody source on the Planckian locus.) For familiarity, the SSI value is scaled to a 100-point scale similar to that of CRI and other metrics In the context of the SSI, a value greater than 90 means there will probably be no issue with rendered colors, while a lower score indicates a greater chance of differences in rendered colors. Note that while a lower score may still produce acceptable color renderings with a particular camera, the low score indicates increased likelihood of rendering differences with a different camera spectral sensitivity.

Although the SSI concept is applicable for most visible spectra, it is primarily intended for use with “white” sources of various color temperatures. The SSI value is always denoted with the reference illuminant used for comparison shown in [brackets]. Thus, for example, an SSI[3200K] value is with respect to a 3200K blackbody source on the Planckian locus. An SSI[D55] value is with respect to the D55 standard daylight illuminant, whereas an SSI[Xenon] value uses the Xenon spectrum for comparison. Although this may raise concerns about a proliferation of numerous reference illuminants, it is believed that the industry will adopt reference illuminants that are already in use by the industry, such as SSI[2700K] for indoor home lighting, SSI[3200K] for incandescent studio lighting, and SSI[D55] for a daylight reference.

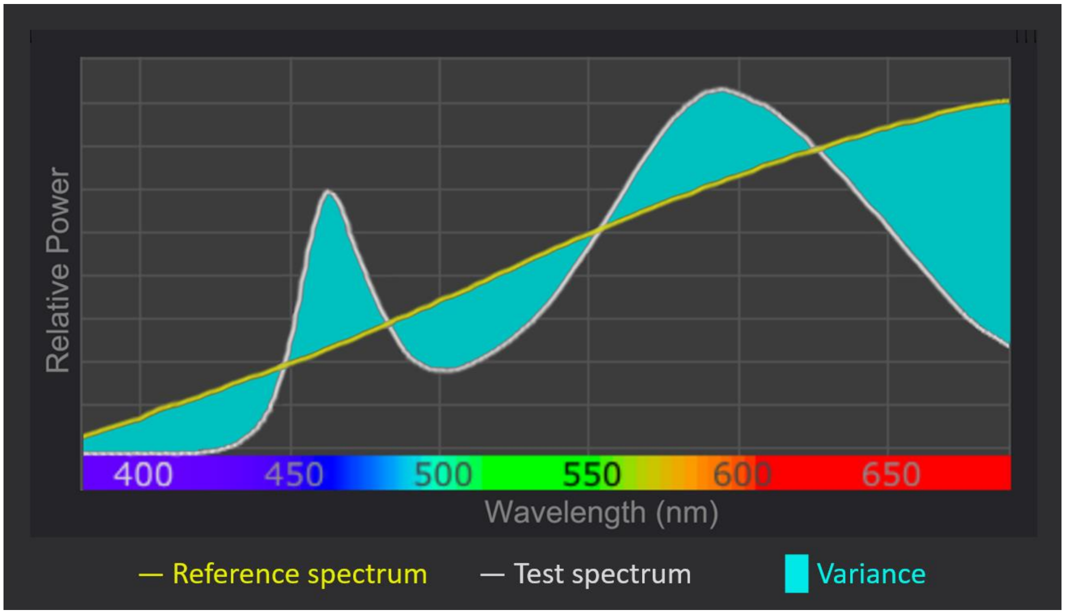

FIGURE 2. A graph of the spectral power distributions of both studio tungsten light (the "reference") and a typical white LED source (the "test"), and the variance between them.

Figure 2 illustrates the difference between the spectrum of a typical tungsten incandescent illuminant (represented by the yellow curve) and that of a typical white LED source of the same correlated color temperature (represented by the white curve), in each case graphing relative power as a function of wavelength across the visible spectrum. The cyan-shaded area shows the variance between the two curves. The SSI concept is based upon the desirability of reducing the variance between these two curves – the smaller the area, the greater the SSI value. Thus, if the variance area is small enough, the spectrum of the test source is effectively the same as the reference source and will produce the same rendered colors as the reference source. The simplicity of the SSI approach allows for relative ease in choosing sources that will provide properly rendered colors with any camera or film stock, and colors that match those as seen by the eye. SSI is useful for cinematography, television, still photography, and human vision use cases.

For example, the spectrum of the source illustrated in Figure 1 has a CRI value of 92, but it has an SSI[3200K] value of 76 due to its peaks and troughs. As mentioned earlier, this illustrates why CRI cannot be used as a predictor of color-rendering accuracy for cameras with differing spectral sensitivities; the lower SSI value more accurately warns of the potential for color-rendering errors. A low SSI value does not indicate what color rendering errors may occur, and indeed sources with the same low SSI value may result in considerable differences in rendered colors depending on the spectral sensitivity of the chosen camera.

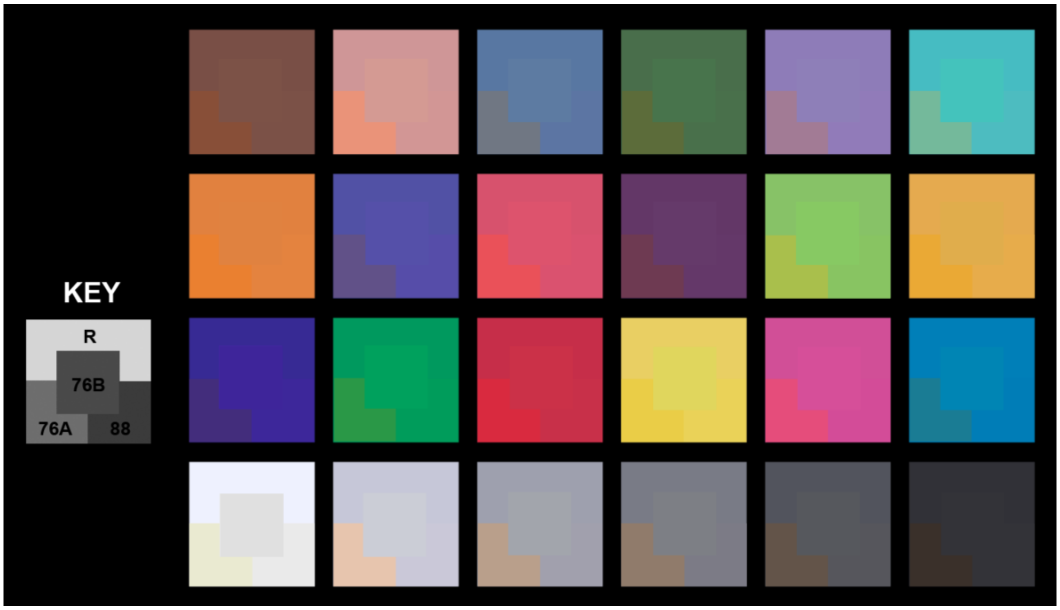

FIGURE 3. Segmented Macbeth chart demonstrating color reproduction differences between light sources with various SSI values as seen by one camera.

Figure 3 illustrates the color rendering differences of various SSI-rated light sources (specified as 3200K) relative to a tungsten reference and a single digital cinema camera. The upper segment of each patch (labeled "R" in the key) illustrates color rendering with tungsten illumination as the reference. The lower left segment of each patch (labeled "76A" in the key) illustrates an example LED light source with an SSI[3200K] of 76, which produces a noticeably different color rendering than the reference illuminant. The middle segment of each patch (labeled "76B" in the key) is a different LED source that also has an SSI[3200K] of 76, but it has a different spectrum which produces rendered colors that are noticeably closer to those produced by the reference illuminant when used with this particular camera. It should be noted that this particular light source might produce less satisfactory results with another camera that might have different spectral sensitivities. Finally, the bottom right of each patch (labeled "88" in the key) illustrates a third example LED source with an SSI[3200K] of 88. With this particular camera, this light source results in relatively good color rendering.

CALCULATION OF SSI

In designing SSI, the range of wavelengths to be included in its calculation was determined by the range of sensitivity of human vision, photographic film, and multiple digital cinema and still cameras. The spectral power distribution data of the test illuminant are "binned" into 10-nm samples to smooth out small peaks and measurement tolerances. The binned values are weighted differently for different regions of the spectrum, in order to place less emphasis on the lower and upper wavelengths where the variations have less overall effect on color rendering results. The values are smoothed using a weighting factor to reduce the effect of minor deviations. The weighting factors and the smoothing values were optimized using Fourier analysis, and the math was simplified using convolution to provide for easy calculations.

SSI is computed from the spectral power measurements of the test source and the reference source as follows:

1) Bin measured test illuminant data into 10 nm samples from 380 to 670 nm using trapezoidal binning function.
2) Normalize to unity total power of reference & test illuminants by dividing each 10 nm sample by sum of all 10 nm samples for each illuminant.
3) Normalized difference vector = Normalized test illuminant vector – normalized reference illuminant vector.
4) Relative difference vector = Normalized difference vector / (normalized reference illuminant vector + mean value of normalized reference illuminant vector).
5) Weighted relative difference vector = Relative difference vector * spectral weighting vector {12/45, 22/45, 32/45, 40/45, 44/45, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 11/15, 3/15}.
6) Add zero to each end of weighted relative difference vector to have 32 values, then convolve with {0.22, 0.56, 0.22} to create smoothed weighted relative difference vector.
7) Metric value = Sum of squared values of smoothed weighted relative difference vector.
8) SSI value = Round [100 – 32*$\sqrt{\text{metric}}$].
9) Indicate reference illuminant within brackets as part of SSI value; use blackbody color temperature in kelvins (e.g., SSI[3200K]) or CIE standard illuminant (e.g., SSI[D55]) or name of reference illuminant (e.g., SSI[Xenon].)

A full specification for the calculation of SSI can be found in Academy S-2018-001.

SSI HIGHLIGHTS

- An index for evaluating luminaires used for motion picture photography, but also applicable to television, still photography and human vision applications
- A single number on a scale of 0 to 100 that indicates the similarity of a test illuminant's spectrum to that of a reference illuminant (typically incandescent or daylight), specified in brackets (for example, "SSI[3400K]: 83", or "SSI[D55]: 87")
- Can be thought of as a "confidence factor" that scene colors will be rendered predictably
- A value of 100 indicates a perfect match to the reference (target) spectrum; values above 90 should be a very good match, between 80 and 90 a pretty good match, and below 60 will probably have color rendering issues
- Considers wavelengths from 380 to 670 nm, with less impact from wavelengths at the low and high ends of the spectrum
- Low-energy spikes and noise are smoothed out

ADDITIONAL INFORMATION

SSI is more fully described in a paper that was presented at the 2016 Society of Motion Picture and Television Engineers (SMPTE) Technical Conference (accessible by SMPTE and IEEE members at http://ieeexplore.ieee.org/document/7819442/). In that presentation, the only reference illuminants postulated were ISO daylight and studio tungsten. During the review phase after the presentation, the

Project Committee decided to add the ability to use other reference illuminants such as blackbody illuminants of arbitrary color temperature and CIE standard illuminants.

An Excel-based SSI calculator can be downloaded from http://oscars.org/SSI. It demonstrates the SSI calculation procedure using tungsten and daylight reference illuminants, and may be modified for use with other blackbody or CIE standard illuminants by replacing the reference illuminant spectral values with those of the desired reference illuminant.

The Academy is currently seeking feedback and the Spectral in advance of its submission to SMPTE for standardization. Questions and comments should be sent to SSI@oscars.org.

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[1] ISO 7589:2002, "Photography – Illuminants for sensitometry – Specifications for daylight, incandescent tungsten and printer," International Organization for Standardization, Geneva, January 02, 2002.
[2] CIE 13.3-1995, "Method of Measuring and Specifying Color Rendering Properties of Light Sources (3rd edition), Commission Internationale de l'Eclairage, Paris, 1995.
[3] CIE S 014-1/E:2006 (ISO 11664-1:2007), "CIE Standard Colorimetric Observers," Commission Internationale de l'Eclairage, Paris, December 1, 2008.